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Title: Exoplanets: Strange New Worlds

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EXOPLANETS
STRANGE NEW WORLDS

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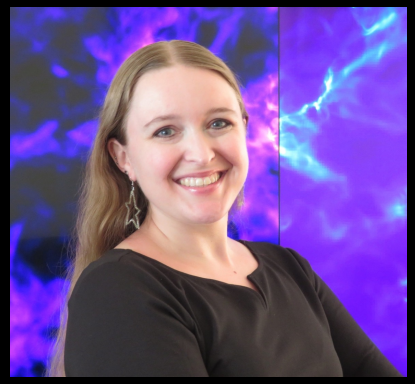
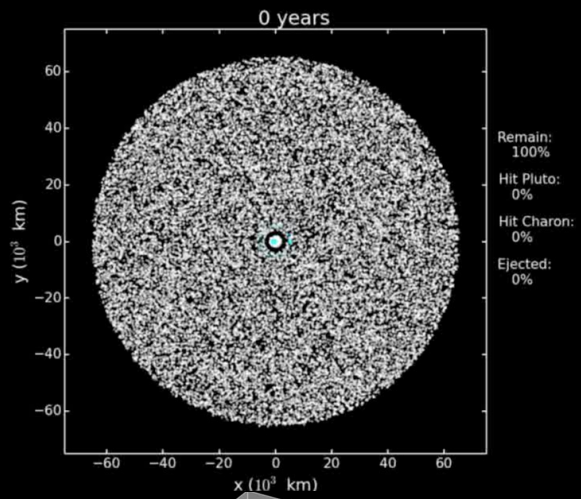
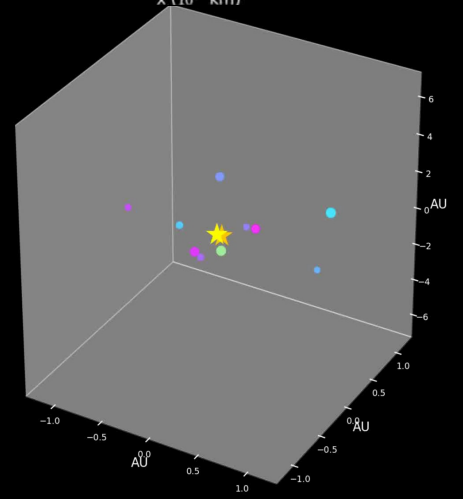
27 April 2021

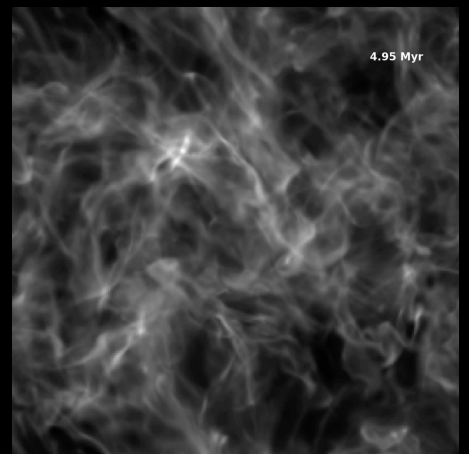
About Me







- Computational astrophysicist @ LANL
  - I use simulations to study things like
    - Pluto-Charon and the Kuiper Belt
    - Exoplanets
    - Star formation



- PhD from University of Arizona (Tucson)
- BS from University of Wyoming (Laramie)
- Hobbies: Books, movies, hiking, travel, cooking, eating…

When you look up at night, what do you see?

You can see by eye
- 1 Moon
- 5 planets
- >5,000 stars

In our Milky Way galaxy
- >100 billion stars
- ~1 planet per star

Image credit: Jeff Hellermann, NRAO

Exoplanet: *noun* A planet that exists outside of our Solar System.

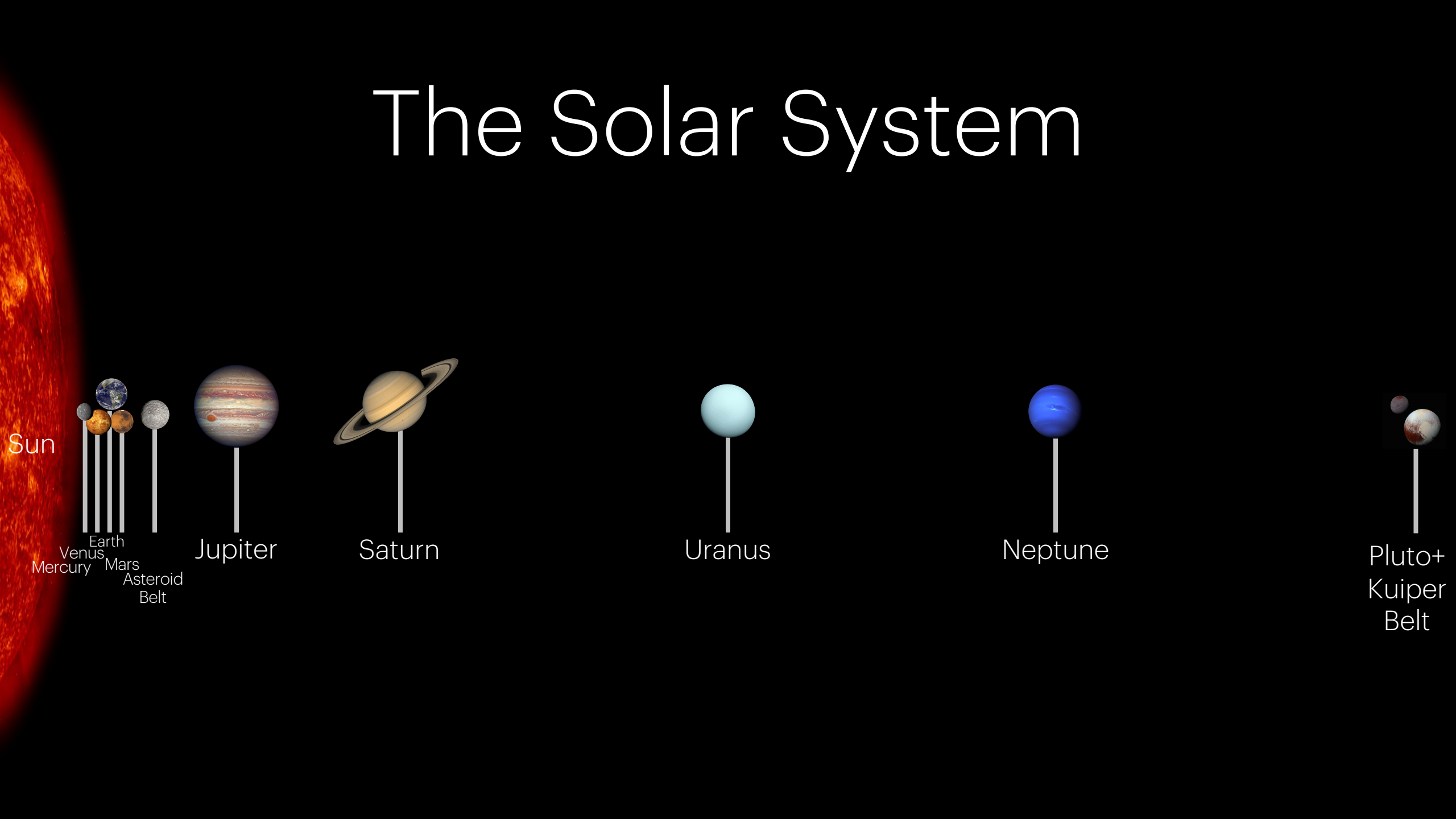
Also sometimes called an *extrasolar planet*

How would you define a ”planet”?

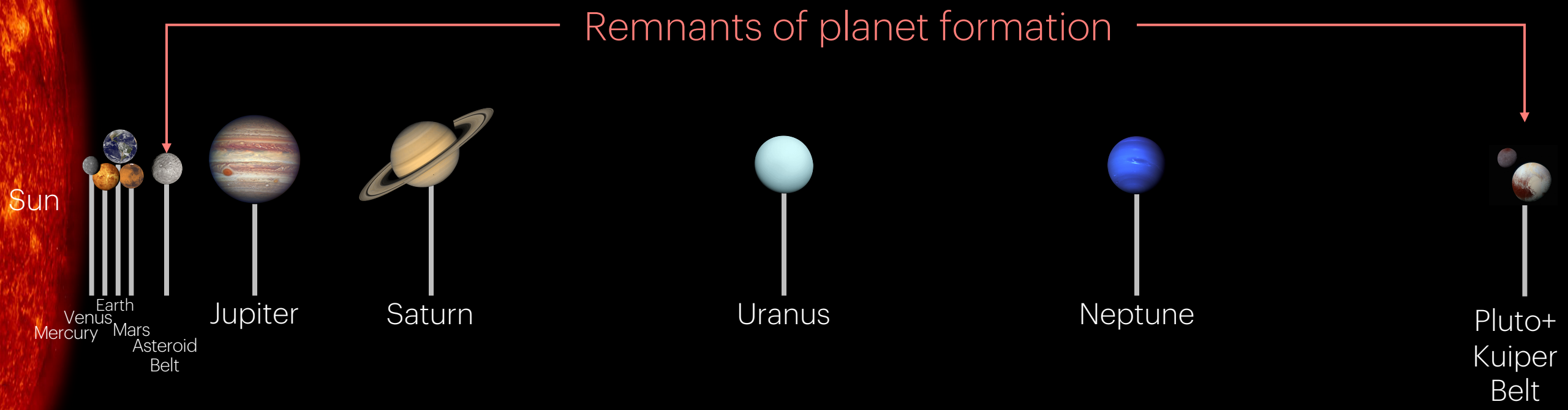
How would you define a "planet"?

- A planet is not a star
  - A planet cannot generate its own energy through nuclear fusion
    - Planet mass less than ~13 x mass of Jupiter
- A planet orbits a star
  - But we have found "free floating" planets without a star!
- A planet doesn't form like a star
  - A planet forms "up" from the accumulation of gas, dust, and rocks ("planetesimals") while a star forms "down" from a larger cloud of gas

The Solar System



The Solar System

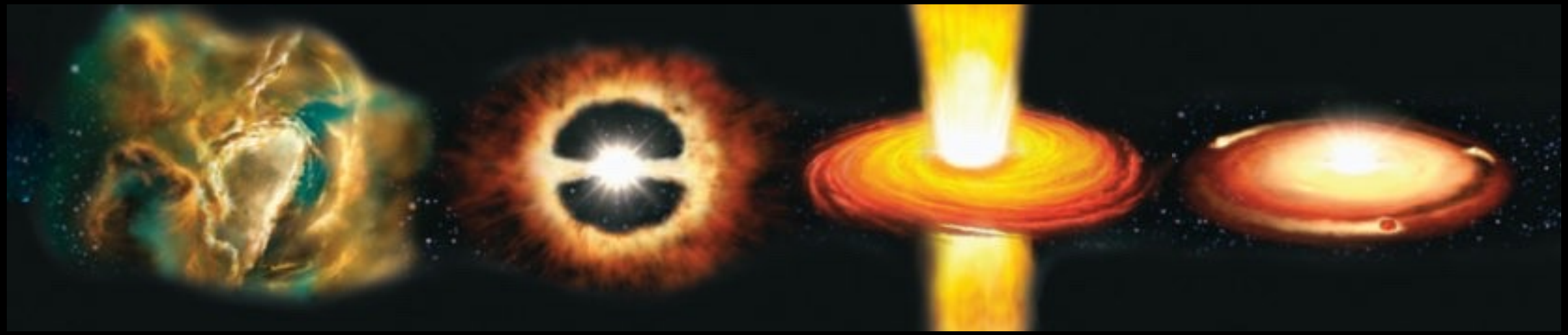


Terrestrial (rocky) planets

Gas giant planets

Ice giant planets

So... why is the Solar System the way it is?
How do planets form?



Begin with a “molecular cloud” of hydrogen gas in space

Cloud collapses due to gravity

A star forms at the center surrounded by a disk

The disk starts to make solids (rocks and ice) from which planets form

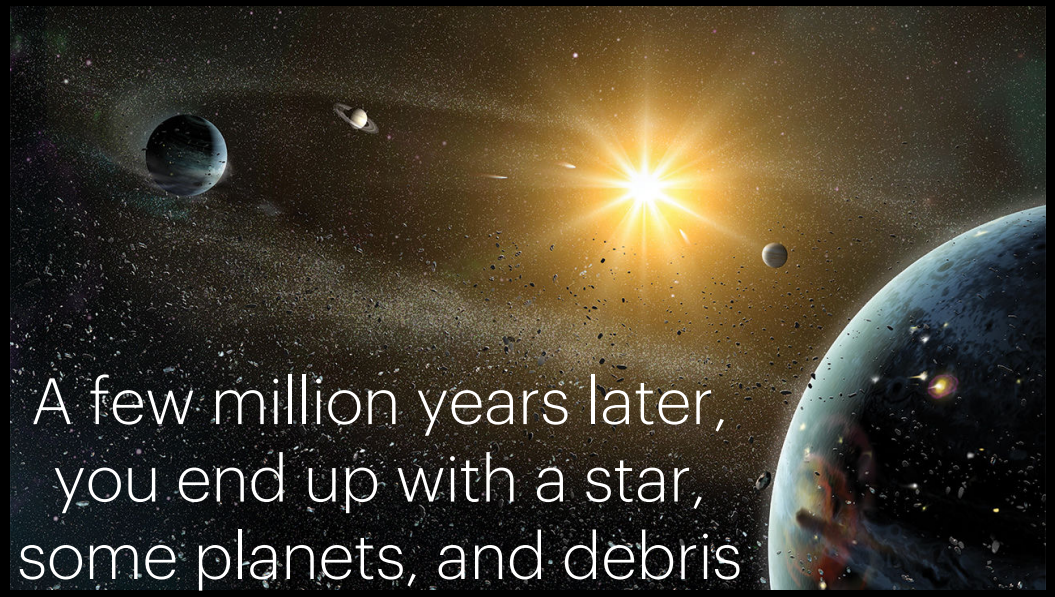
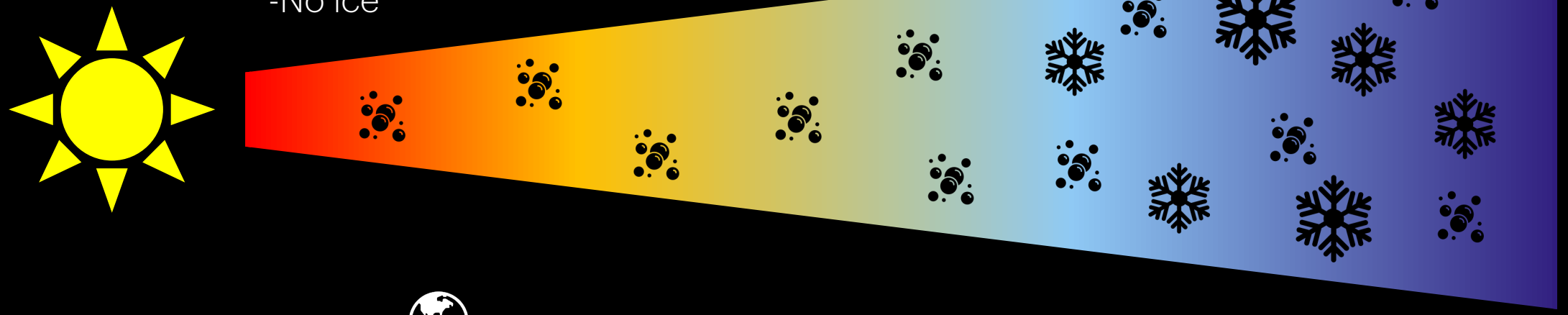


Image credit: HIW/Nat Geo

Why are planets where they are?

Hot!
-Not a lot of material
-No ice

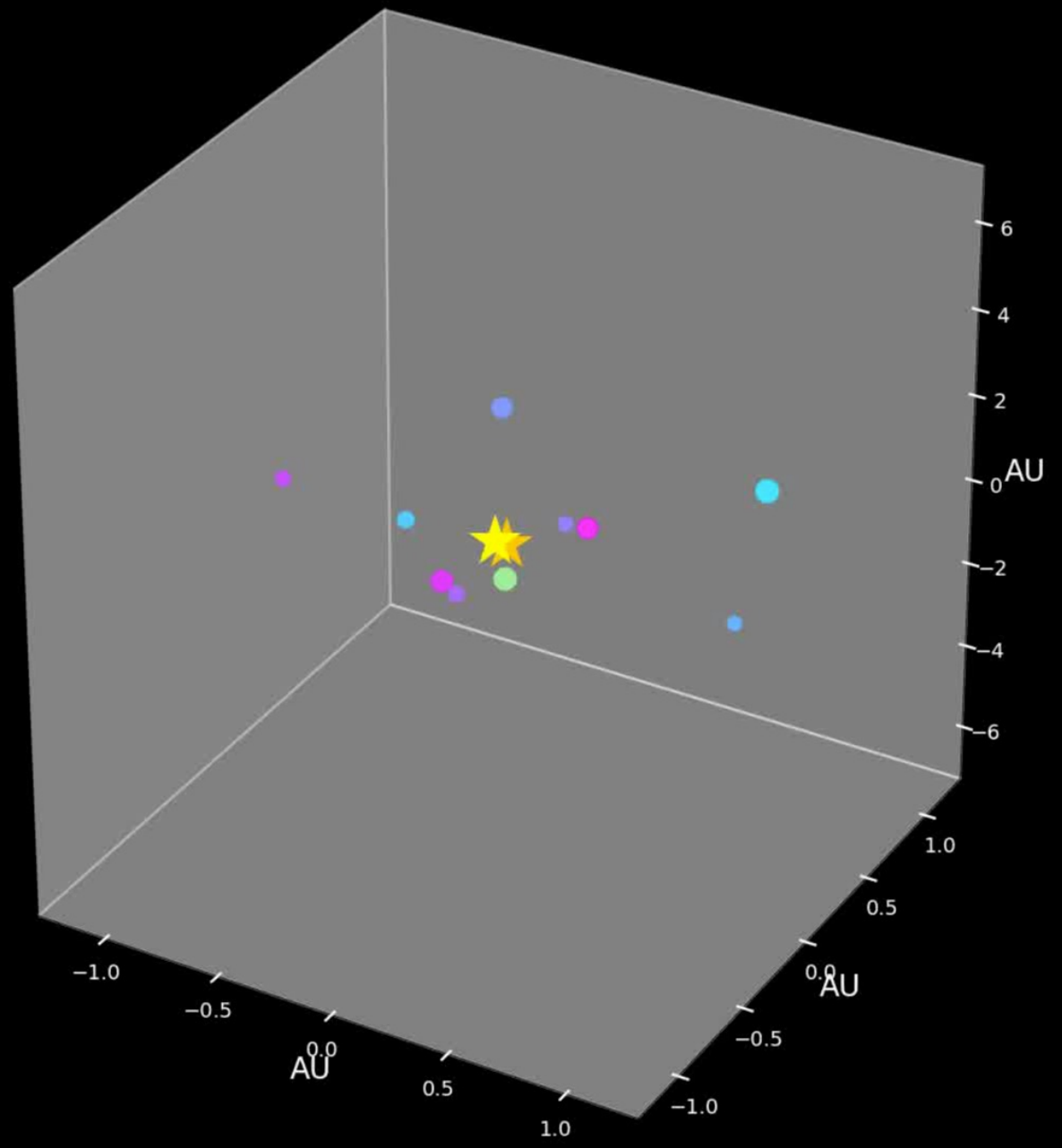
Cold!
-Lots of gas, dust, rocks, and ice



Small, rocky planets

Big, gas/ice planets

But, planets don’t have to stay where they formed



Smullen et al. 2016

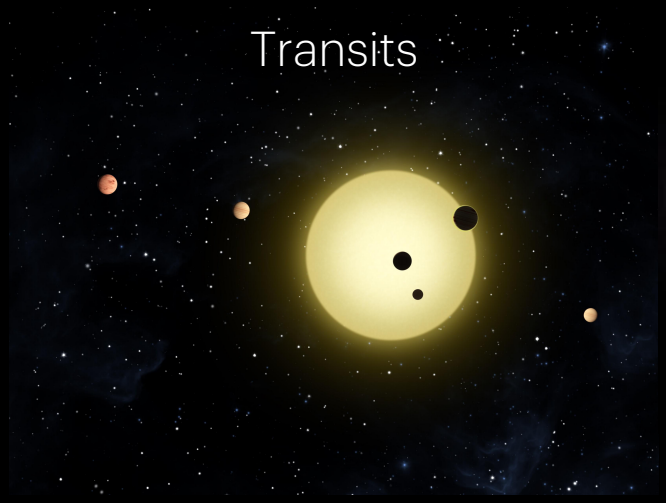
Now that we know what planets to look for and where, how do we find them?

Finding Exoplanets

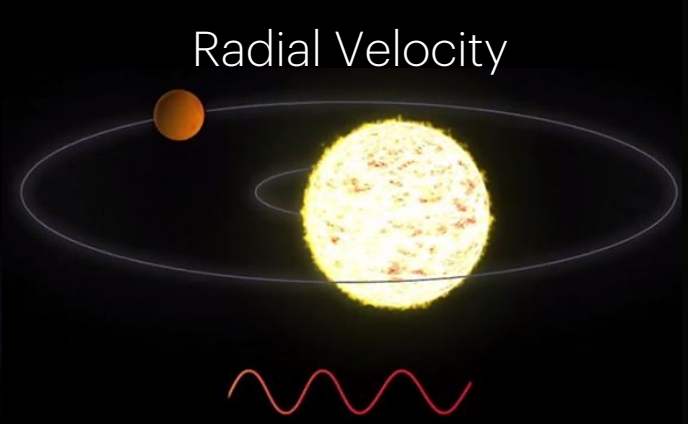
All* astronomy is about interpreting the light our telescopes receive.

There are four main ways we find planets

Transits



Radial Velocity



Direct Imaging

Microlensing

Image credits: Universe Today, NASA, ESO, ESA

*Except for gravitational waves, but that's for a talk by someone else

Transits look for planets blocking light from their star

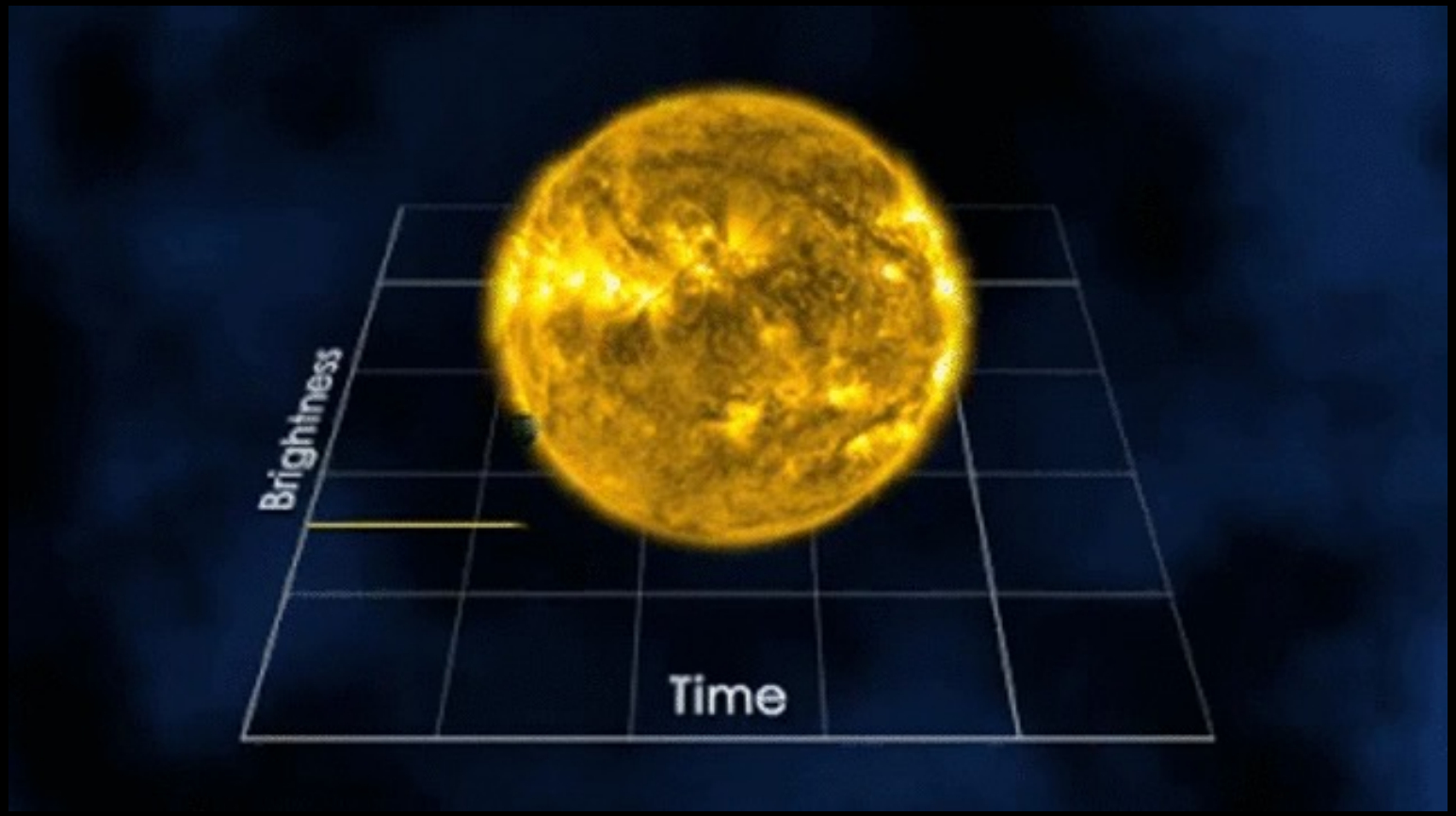


Image credits: NASA

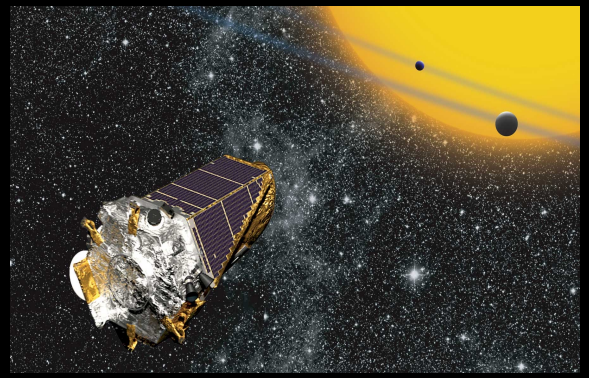
Transits look for planets blocking light from their star

Good for:

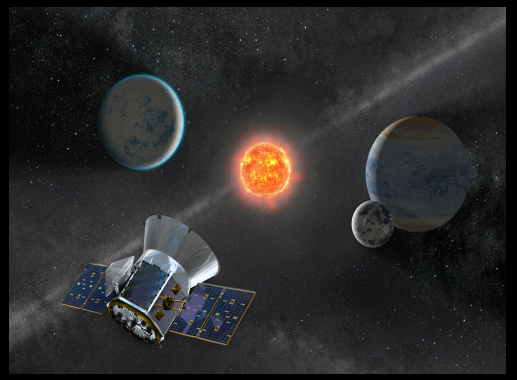
- Most planets close to their star
- Easy to monitor many stars

Bias:

- Planets must orbit in a thin plane
- Hard to find small/distant planets



Kepler Space Telescope



TESS

Image credits: NASA

Radial velocities look for variations in star's velocity due to a planet

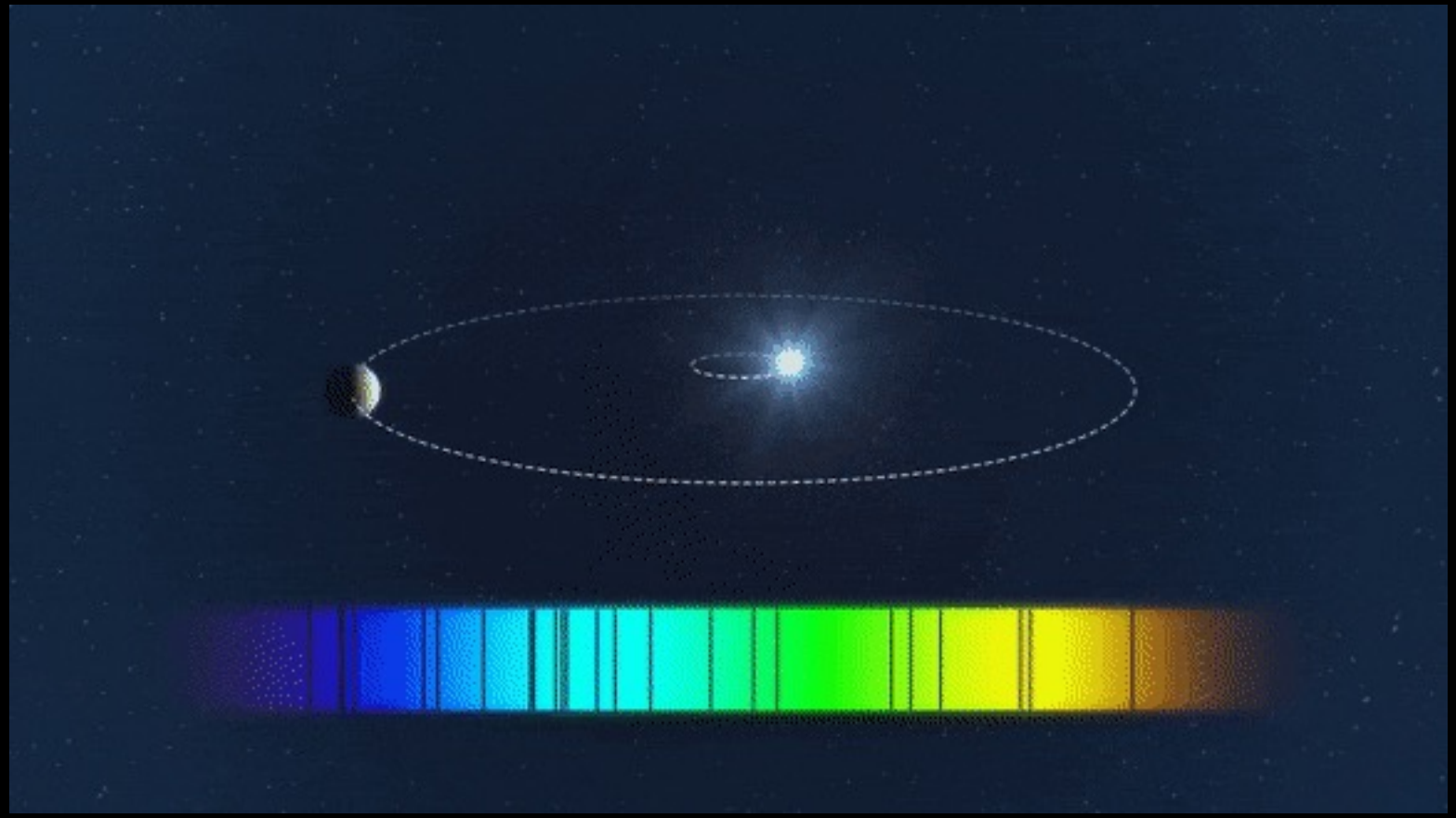


Image credits: ESO

Radial velocities look for variations in star's velocity due to a planet

Good for:

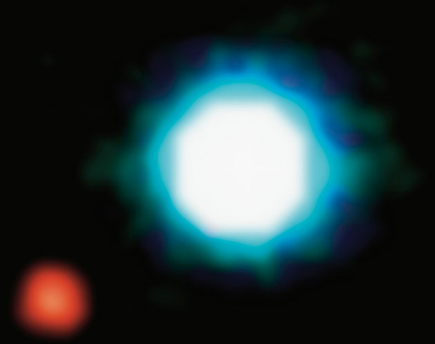
- Mostly big planets
- Easy to monitor stars over long time

Bias:

- Takes a lot of telescope time
- Harder to find small /very distant planets

HARPS instrument at La Silla

Image credits: ESO



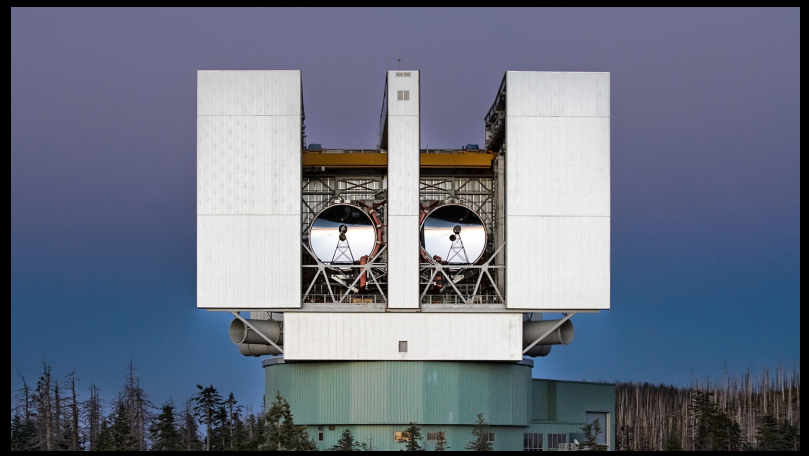
Direct imaging takes pictures of planets

Good for:

- Really big, young, bright planets
- Get a lot of info about the planets

Bias:

- Only find big planets far from the star, which are rare



Large Binocular Telescope

Very Large Telescope

Image credits: UA, ESO

Microlensing looks for planets that act as a “gravitational lens”, magnifying a background star

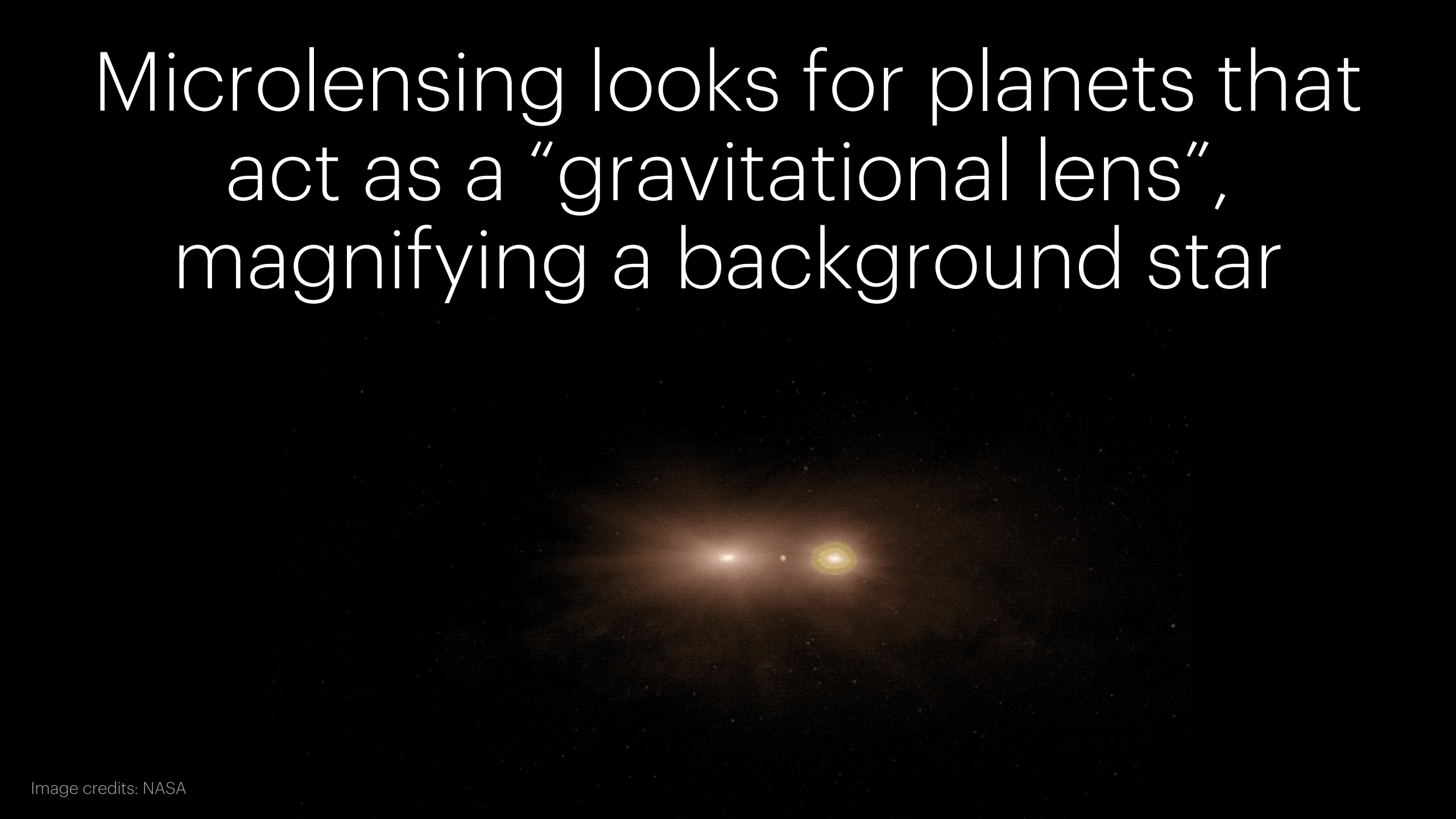


Image credits: NASA

Microlensing looks for planets that act as a “gravitational lens”, magnifying a background star

Good for:

- Any size of planet at mid- to far distance from the star

Bias:

- Can’t follow the planets up to confirm!

OGLE Telescope

Image credits: OGLE

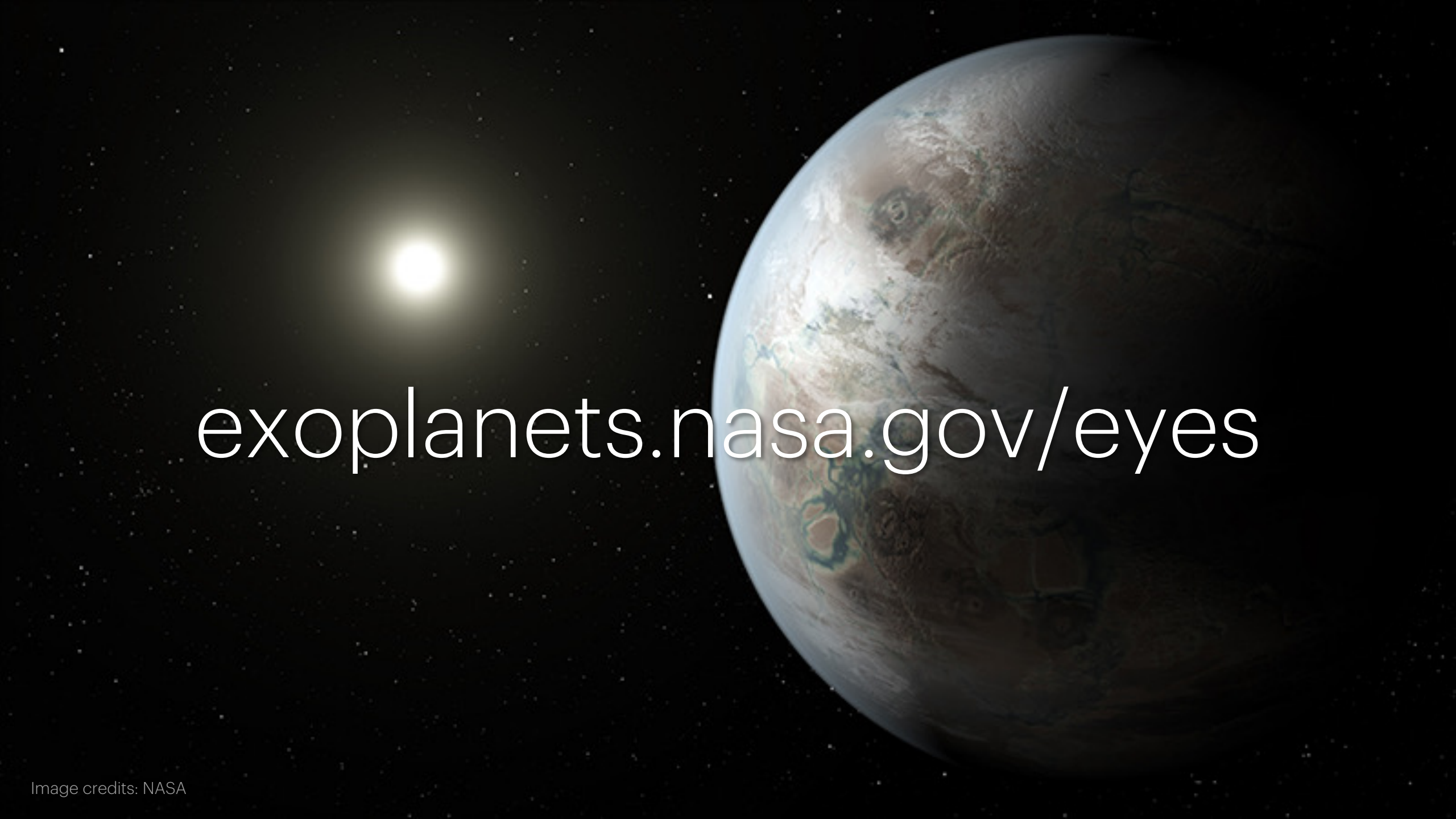


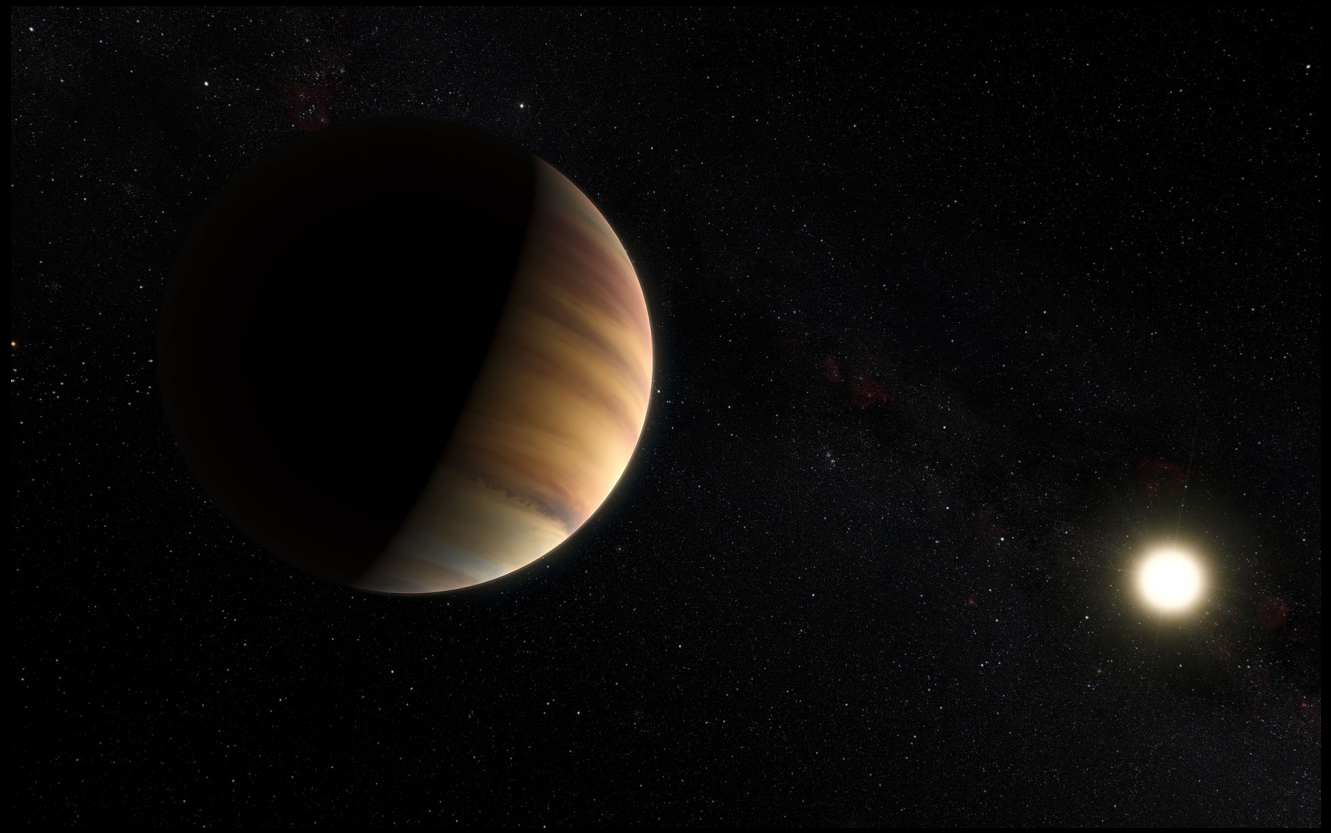
Image credits: NASA

Accounting for biases in observations, there is at least one planet per star (on average).

And remember that there are 100 billion+ stars in our galaxy

Cassan et al. 2012

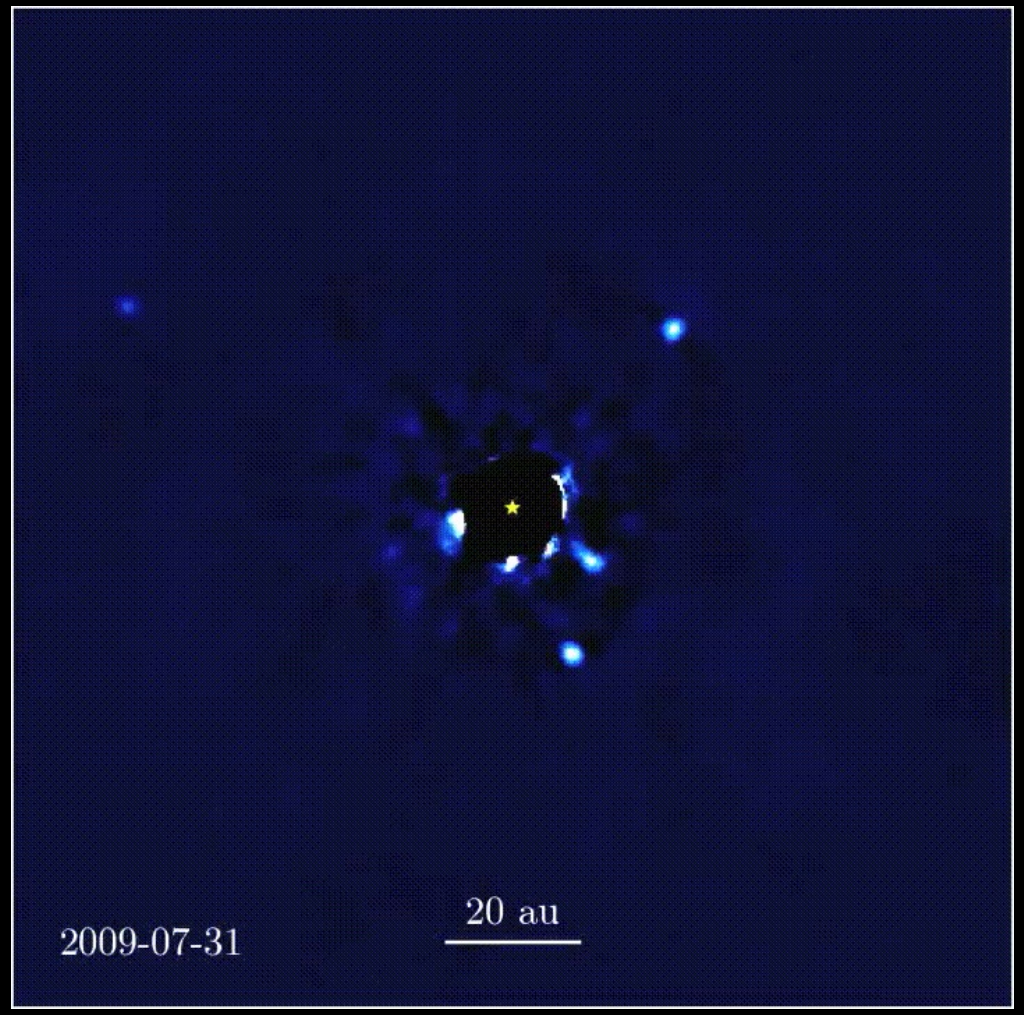
51 Pegasi b



- First planet *ever* found around a Sun-like star
  - Found 1995
  - 2019 Nobel Prize in Physics
- 0.5 Jupiter mass planet with 4 day orbit

Image credits: ESO

HR 8799 b,c,d,e



- Four directly-imaged giant planets!
- Orbits take between ~50—500 years

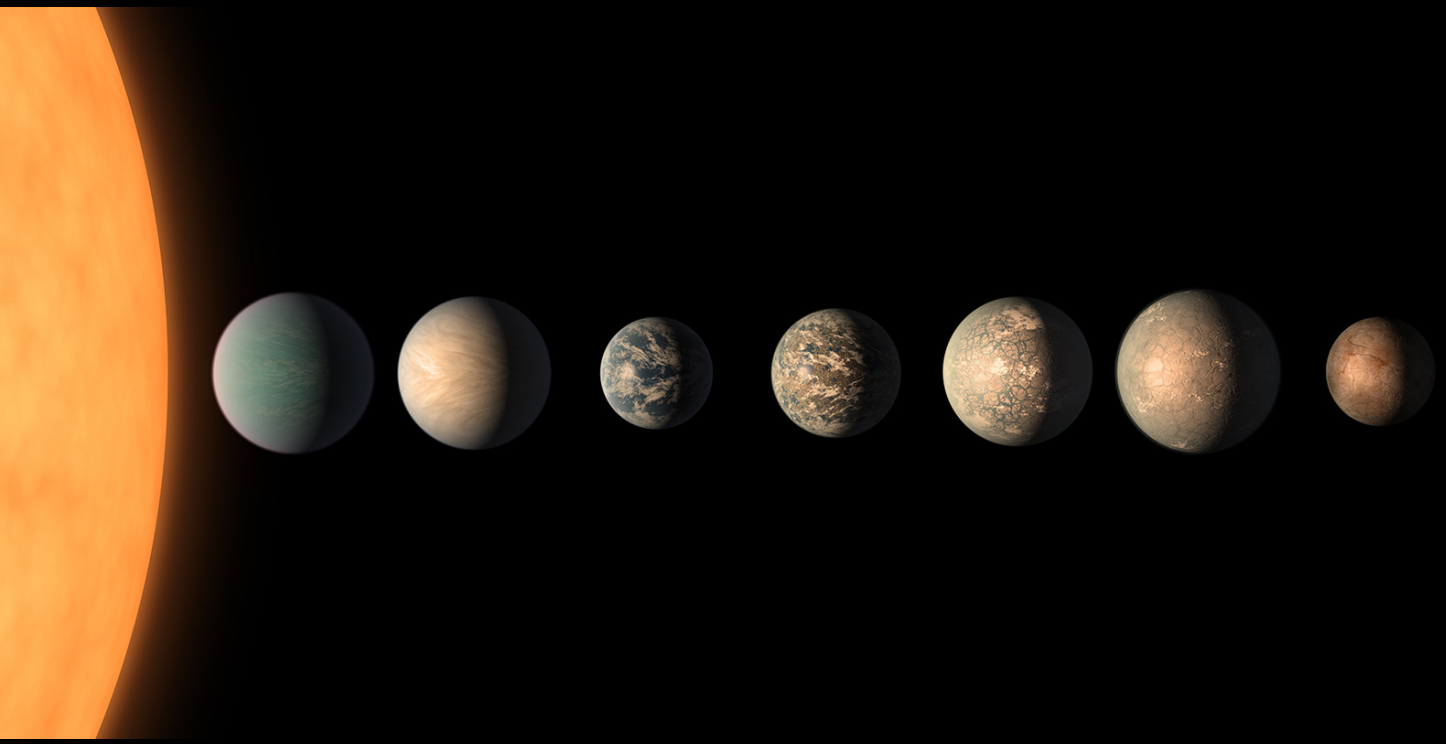
Image credits: Keck Observatory

Kepler-47 b,c,d

- Three ~Neptunes that orbit two stars!
- Called “circumbinary” planets

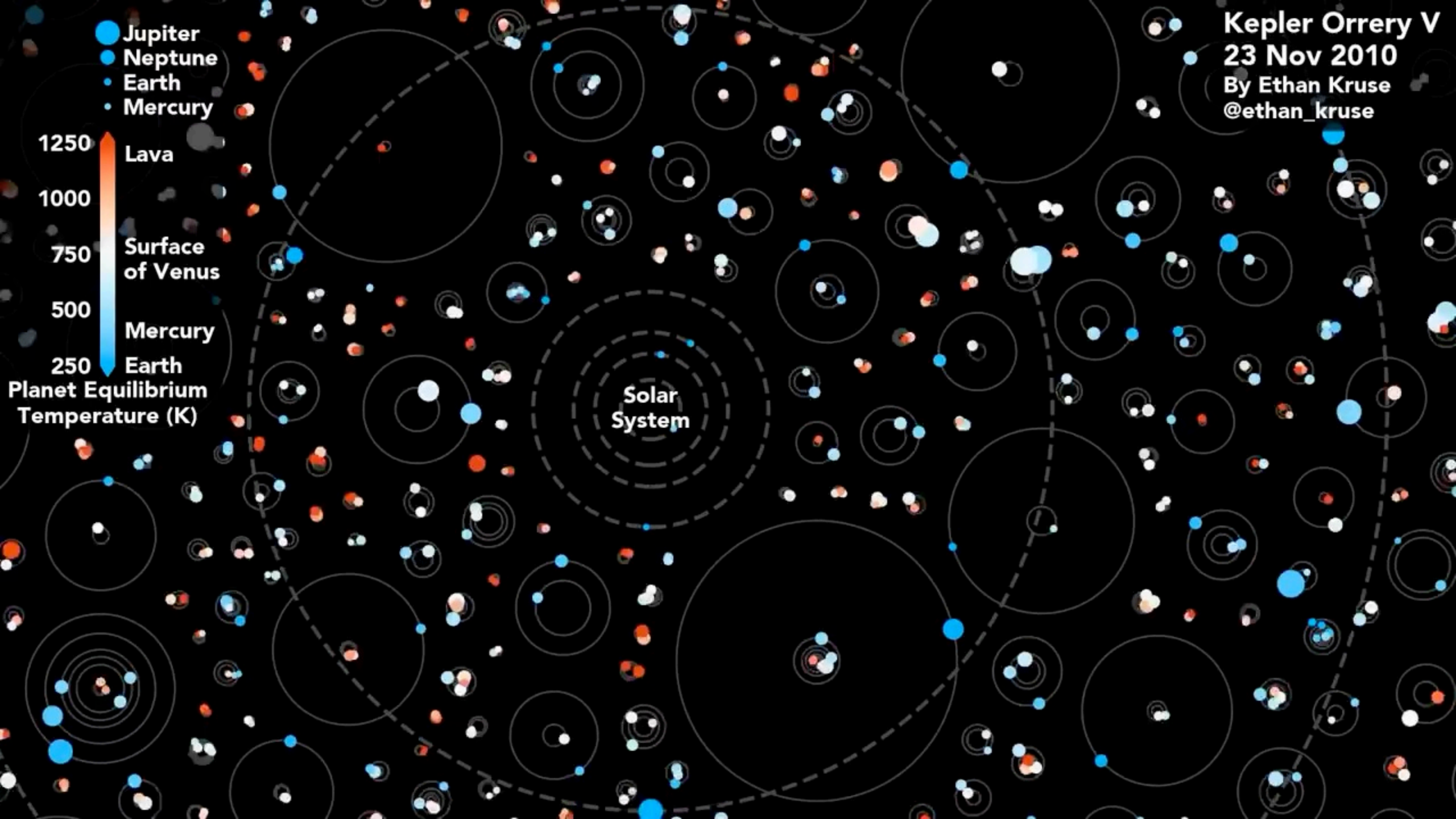
Image credits: NASA

TRAPPIST-1



- 7 Earth-sized planets that orbit in <20 days
- Orbits are a configuration called a “resonant chain”

Image credits: NASA


Jupiter
Neptune
Earth
Mercury
1250
Lava
1000
750
Surface of Venus
500
Mercury
250
Earth
Planet Equilibrium Temperature (K)
Solar System
Kepler Orrery V
23 Nov 2010
By Ethan Kruse
@ethan_kruse

What about finding the next Earth?

What makes a planet habitable?

Image credits: NASA

The Goldilocks Zone

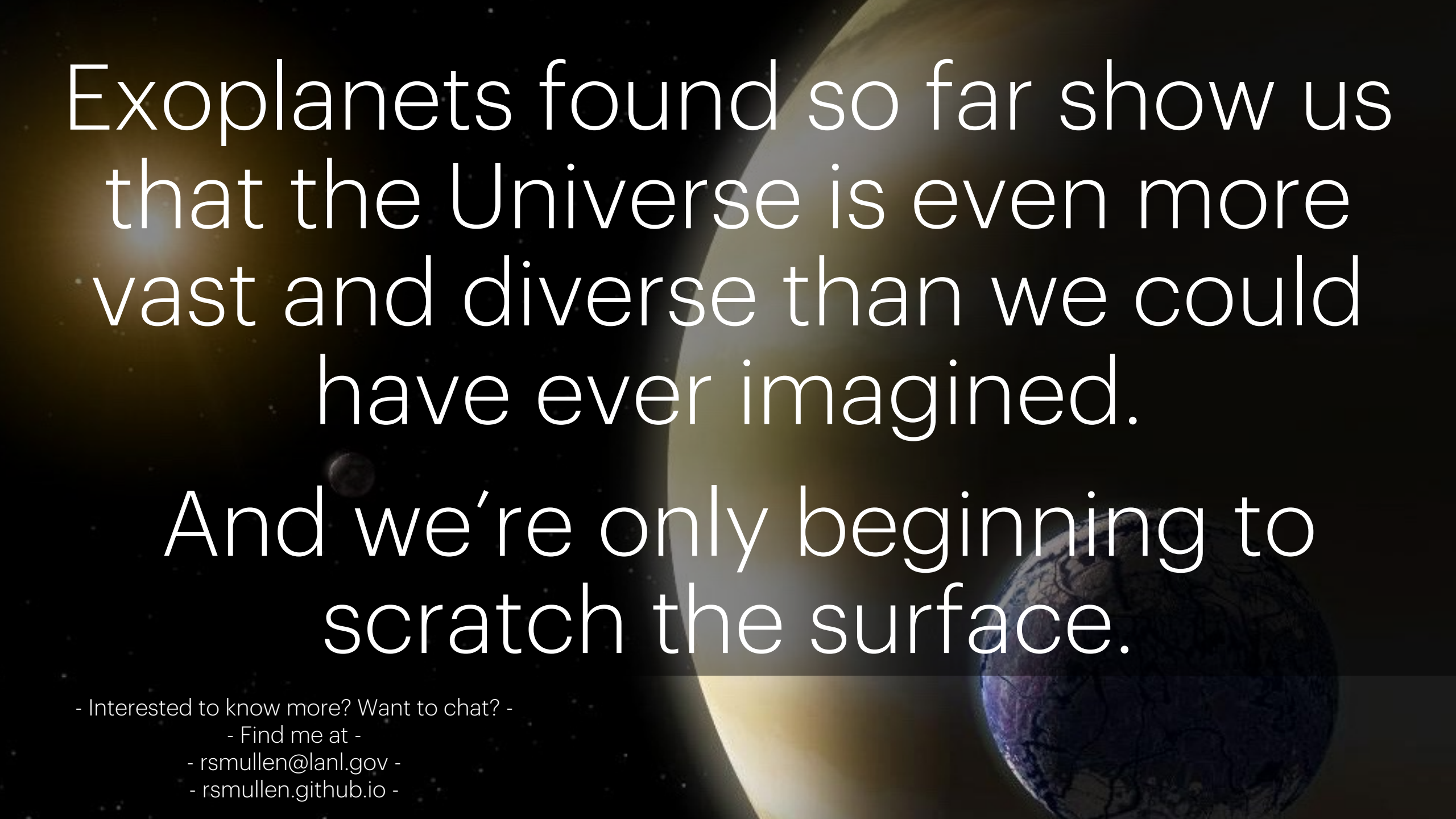
Liquid water is thought to be one of the most important factors for life on Earth

- Need to be far enough (but not too far) from the star so that the planet is warm, not hot or cold
- Need a star that's not too crazy, so something like the Sun
- Need an atmosphere to protect you from space weather

Image credits: NASA

Kepler estimates that $\eta_{\oplus}$ —the number of habitable Earth-like planets per Sun-like star— is **at least 1 in 3**.

Bryson et al. 2021



Exoplanets found so far show us that the Universe is even more vast and diverse than we could have ever imagined.

And we're only beginning to scratch the surface.

- Interested to know more? Want to chat? -
- Find me at -
- rsmullen@lanl.gov -
- rsmullen.github.io -